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EXPERIMENTAL INVESTIGATION ON STRENGTH CHARACTERISTICS OF CONCRETE USING TYRE RUBBER AS AGGREGATES IN CONCRETE

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ABSTRACT

About 80 million tyres are part of 33 million vehicles manufactured in India in 2011. The usage of tyres for burning in cement kilns is up to 20000 tonnes per year. Landfill has been one of the methods for their disposal, however as rubber tyres are not biodegradable, they remain in the land for a long time causing environmental hazard. An alternative for this waste is use of the material in Concrete-A widely used material. In this paper an attempt is made to study the various properties of rubber. An attempt to design concrete of 25Mpa using artificial sand, Shredded rubber and crumb rubber as a source of aggregate is made, using IS 10262:2009. A comparison with control mix mainly their compressive strength, split tensile strength & flexural strength, which uses conventional material will allow assessing the suitability of using shredded aggregate and crumb rubber in concrete as percentage replacement, for structural applications. An attempt is also been made to coat the shredded Rubber particles with NAOH solution and use the same in concrete.

KEYWORDS: Tyre Rubber, Rubberized Concrete, Shredded Rubber, Crumb Rubber, Compressive Strength, Split Tensile Strength

INTRODUCTION

About 80 million tyres are part of 33 million vehicles manufactured in India in 2011 [1]. After the use of these tyre, the waste generated are used typically for land filling, burning in cement kilns. However rubber tyre being a non-biodegradable material and burning causes emission of harmful gases, they add towards environment hazard. In India the usage of tyres for burning in cement kilns is up to 20000 tonnes per year. In industries, large amount of waste tyres are utilized as fuel, pigment soot, in bitumen pastes, roof and floor covers and for paving industries. [1] A tyre is made of natural rubber (also called virgin rubber), Styrene-Butadiene Rubber (SBR), Polybutadiene Rubber (PBR), Carbon black, Nylon tyre cord, rubber chemicals, steel tyre cord and Butyl rubber [1]. These tyres after their use are cut and shredded into chips and shred. The concrete mixed with waste rubber in form of chips and shred added in different volume proportions is called rubberized concrete [2]. Such type of concrete is usually used in manufacturing of reinforced pavement and bridge structures which have better resistance to freeze and ice thawing salts [3,7].Thus when rubberized concrete is used the following issues should be compared and evaluated when considering the application of such materials in the concrete: Collection, processing and transport costs of scrap tyres, Reduction in the environmental costs of land filling and increase in landfill voids and Saving in the virgin materials used to make concrete, can be taken care by substituting tyre rubber in concrete (3-7).

OBJECTIVE OF THE STUDY

The objective of the present study is to analyse the Compressive strength, split tensile strength and flexural strength of concrete made by utilizing waste tire rubber. Recycled waste tire rubber has been used in this study to replace the fine and coarse aggregate by weight with different percentages. An attempt is also made by pre-treating the rubber with sodium hydroxide (NAOH) solution and using the same in concrete as percentage replacement to aggregate content. The study consists of 3 parts:

- Concrete, made with 1%, 5% and 10% replacement of Shredded rubber (without NAOH treatment) of total aggregate content.
- Concrete made with 1% replacement with shredded rubber (with NAOH treatment) of total aggregate content.
- Concrete made with 1%, 2% and 5% replacement with crumb rubber, of total aggregate content (without treatment).

LITERATURE REVIEW

The use of recycled tires as partial aggregate in concrete has been considered for several years. Previous research conducted show dramatic changes in the mechanical properties of concrete when rubber is introduced to the mix [2-14]. A rubcrete mixture generally has a reduced compressive strength that may limit its use in certain structural applications, it possesses a number of desirable properties, such as lower density, higher toughness, lower brittleness index values, higher impact resistance, enhanced ductility, and more efficient sound and heat insulation compared to conventional concrete. Structural applications involving rubcrete may still be possible if appropriate percentages of rubber aggregates are used.

It is also possible to produce relatively high-strength rubcrete mixtures by using magnesium oxychloride cement, which achieves better bonding characteristics to rubber and greatly improves the performance of rubcrete mixtures. In addition, the adhesion between the rubber particles and other constituents of the rubcrete matrix can be improved by pretreating the rubber aggregates [4, 5]. Replacement of rubber particles in concrete by 7.5% and 10% reduces compressive strength of concrete by 10 to 23%, compared to the normal concrete. The tensile strength of concrete reduces by 30% to 60% when rubber is replaced by 7.5% to 10% [6] .The effect of replacing 5%, 7.5% and 10% by weight of coarse aggregates by chipped tyres and the same replacement ratios for cement by powder tyre Crumbs, were investigated. The results showed a reduction of 5% for 5% replacement. Replacement of 7% and 10% showed a reduction of 10-23% in compressive strength. The reason for reduction in the strength includes:

- As the cement paste containing rubber particles surrounding the aggregates is much softer than hardened paste without rubber, the cracks would rapidly develop around the rubber particles during loading and expand quickly throughout the matrix, and eventually causing accelerated rupture in the concrete.
- Due to lack of proper bonding between rubber particles and the cement paste (as compared to cement paste and aggregates), a continuous and integrated matrix against exerted loads is not available. Hence applied stresses are not uniformly distributed in the paste. This is causing cracks at the boundary between aggregate and cement.
- During casting and vibrating the rubber particles tend to move upwards. A high concentration of these particles does happen on the top surface because of low specific gravity. Non-uniform distribution of these particles at the

top surface tends to produce non homogenous samples and leads to reduction in concrete strength at those parts resulting in failure at lower stresses.

- As rubber has lower stiffness compared to aggregates, presence of rubber particles in concrete reduces concrete mass stiffness and lowers its load bearing capacity. The slight increase in compressive strength of sample containing 5% chipped rubber can be due to improvement of the coarse and fine aggregates grading [7]. Compressive strength of concrete with 100% replacement of chipped rubber showed 90% reduction. However reduction in strength was 80% when crumb rubber was used as 100% replacement to sand in concrete [8].Concrete specimen with cement dosage of 300 and 0.5 water cement ratio and 0%,10%,20% and 30% rubber aggregate(made from waste tyre) in volume with 20m conditions of freeze –thaw, sea water and high temperature was made. Increasing rubber ratio in concrete has negative effects on concrete durability. The damage as a result of freez-thaw in the concrete of RC-10 set was less than damage in control concrete. Rubberized concrete can be used in environment where high temperature does not exist. It is recommended that the rubberized mortar be kept in sea water, cement with higher strength, and cement resistant to sulphate could be used [9]. Maximum loss of 51.9% for concrete mixtures containing fine Tyre Aggregate was noted in Compressive strength of concrete and for splitting tensile strength, with similar trends, the maximum decrease was 48.3%. The modulus of elasticity had a maximum loss of 39.3%, also for the mixture with 15% tyre aggregate. The only property that improved with the replacement of Natural Aggregate by Tyre Aggregate (TA) was abrasion resistance, which decreased 66.0% for a 15% replacement of coarse TA and Fine TA, although there were some reservations about the reliability of this test on concrete containing used tyre rubber aggregate [10]. Reduction of 28 days compressive strength by 15%, 25%, 50% and 67% for replacement levels of 25%, 50%, 75% and 100%, when crumb rubber was used to replace fine aggregate. Similarly chipped rubber, as replacement to coarse aggregates shows reduction of 28 days compressive strength by 40%, 48%, 73% and 78% for replacement levels of 25%, 50%, 75% and 100% respectively [11]. When rubber particles are added in cement paste (rubber particle had a size with maximum 500μm), NAOH solution was used in order to decrease hydrophobic nature of rubber surface. At first, the surface of rubber particles were modified by saturated NAOH solution for 20 min. The rubber particles treated by NAOH show better cohesion with cement paste, indicating that there was an improvement in flexural strength by this procedure, but a 33% decrease occurred in compressive strength [12].Strains of the concrete with the same compressive strength with rubber waste from used tires (3.2% from aggregate by mass)deformation are 56%-63% higher after the static loading, while set deformations after the unloading is 219%-360% higher than for the none rubberized concrete [13]. The 7- day and 28- day compressive strength of the specimens increased by addition of silica fume to concrete containing crumb rubber. This happens because of filling capability of silica fume fine particles as well as good adhesion between the rubber and the cement paste. Addition of 2 and 3% Nano silica to rubber-containing specimens results in the increase of 7- day and 28- day compressive strength in comparison with those which only contain crumb rubber. Compressive strength increment of rubber-containing concrete in the presence of silica fume was higher than Nano silica and their mixtures [14]. Although it is not recommended to use this rubberized concrete in structural elements where high strength is required, it can be used in many other construction elements like partition walls, road barriers, pavements, sidewalks, etc. which are in high demand in the construction industry [15].

EXPERIMENTAL PROGRAMME

An experimental program was undertaken which consisted of testing properties of shredded rubber tyre (SR) and crumb rubber (CR) as aggregates and properties of fresh and hardened concrete specimens made using SR and CR. The procedures for the programme were followed according to relevant BIS.

Materials Used

- **Conventional Materials:** Cement (C), Artificial aggregates (AFA) and coarse aggregates (RA-20mm), purchased from the local vendors.
- **Superplasticiser (A):** Fosroc –Conplast SP500 complies with IS: 9103:1999 and BS: 5075 Part 3. Conplast SP500 conforms to ASTM-C-494 Type 'G'.
- **Crumb Rubber (CR):** Crumb rubbers are obtained by grinding. Crumb rubber- 30 mesh is produced by passing rubber tires through a screen with 30 holes per inch resulting in rubber granulate that is slightly less than 1/30th of an inch. Refer Figure 1

Figure 1: Crumb Rubber Figure 2: Shredded Rubber

- Shredded Rubber (SR): This fine grade reclaim rubber product is manufactured from whole tyre scrap. These are the used tires from passenger car used tyres, primary shred size of pieces from 30 cm and below, the shred is the primary cut of used tires produced by elden primary chopper, container 40 ft load with 25 tons. Refer Figure 2 CR and SR Were purchased from local vendors.

Experimental Programme

The various mixes designed were as per the guideline laid down by IS 10262:2009 (16) for M25 grade concrete with target strength as 31.6 N/mm2. The mixes designed were

Mix 1: C +AFA +RA-20mm) + A

Mix 2: C+ AFA +RA-20mm +5%SR +A,

Mix 3: C+ AFA +RA-20mm) + 10%SR+A

Mix 4: C+ AFA +RA-20mm) + 1%SR+A

Mix 5: C+AFA+RA-20mm+1% SR (treated with NAOH) + A

Mix 6: C+AFA+RA-20mm+5%CR+A,

Mix 7: C+AFA+RA-20mm+2%CR+A,

Mix 8: C+AFA+RA-20mm+1%CR+A,

Mix 9: C+AFA+RA-20mm+1%CR (Treated with NAOH) + A

RESULTS AND DISCUSSIONS

Properties of Materials

The surface texture of shredded rubber (SR) can be seen in the figure 2. It is smooth, irregular and having nylon fibers imbedded in the rubber. The structure of SR depends upon the method of shredding tyres and/also the type of tyre which is being shredded. The fineness modulus, which is the indication of coarseness or fineness of a sample, of AS and SR was found which yielded the results as 3.05 and 4.641 respectively. The results indicate that SR is much coarser. An attempt to use SR as aggregate in concrete needs proper designing and also can be done in percentages and 100% replacement may not be done. Specific gravity of SR and AS are 0.967 and 2.89 respectively. Specific Gravity of CR is 0.595. This indicates that the SR and CR are lighter than that of artificial aggregates or conventional coarse aggregates. The main reason for this is the structure and presence of nylon fibers in SR and CR. Water absorption is an important factor however for SR and CR it is attributed to the water clinging to its surface. Loose Bulk density of SR is 0.49 kg/lit and for AS is 1.35kg/lit. The lesser value of loose bulk density of SR is attributed to the structure of SR (Refer Table 1 and Table 2).

Table 1: Properties of Fine Aggregate

Property of Aggregate	NCA-20mm
Specific Gravity	2.86
Elongation Index	34.82%
Flakiness Index	14.7%
Loose Bulk Density	1.41kg/lit
Water Absorption	1.37%
Impact Value	16.22%
Crushing Value	21.67%

Table 2: Properties of Coarse Aggregates

Property of Aggregate	AFA	SR
Specific Gravity	2.89	0.967
Fineness Modulus	3.05	4.641
Moisture Content	2.83	-
Loose Bulk Density	1.35kg/lit	0.49 Kg/lit
Water Absorption	3.86%	-
Material finer than 75µ	2.85%	-

Properties of Fresh Concrete

Properties of fresh concrete were mainly judged by workability by slump test. The values of slump tests for control mix and each replacement of shredded rubber are as shown in the Table 3.

Table 3: Results of Mixes

ID	Mix Proportions (M25)	Slump mm	28day Compressive Strength N/mm2	Split Tensile Strength N/mm2	Modulus of Rupture N/mm2	Density
Kg/m3			28 Days	28 Days	28 Days	Kg/m3
Mix 1	1:2.22:4.07, W/C – 0.47	68	32.66	3.41	3.46	2715.06
Mix 2	5% Replacement of SR with total aggregate content	-	15.57	1.52	5.53	2480
Mix 3	10% Replacement of SR with total aggregate content	-	7.82	0.80	2.19	2195.55
Mix 4	1% Replacement of SR with total aggregate content.(without NAOH)	-	30.98	3.15	3.15	2560.98
Mix 5	1% Replacement of SR with total aggregate content.(With NAOH)		31	3.23	3.9	2660.74
Mix 6	5% replacement of crumb rubber	-	11.49	0.88	4.23	2432.59
Mix 7	2% replacement of crumb rubber	-	14.94	1.95	3.1	2457.28
Mix 8	1% replacement of Crumb rubber	-	20.45	2.65	3.12	2476.05
Mix 9	1% replacement of Crumb rubber(with NAOH treatment)	-	21.45	2.95	3.25	2490.02

The results shows that use of superplasticser contributed towards better workability with the same w/c ratio. However with 10% and 5% replacement of SR the workability as in terms of measurement showed a slump of 300mm. However further observation showed that the 300mm slump showed a slight buckling pattern (refer Figure 3 and Figure 4), the fact that the shape of SR -interlocking actions of wire, contributed towards holding the concrete and thus avoid the collapse of concrete. Concrete In general, the rubberized concrete samples showed acceptable workability in terms of ease of handling, trowelling, placement and finishing. The reduction in the workability of the concrete can be attributed to a combination of the lower unit weight of the wet mix and higher friction between the rubber aggregate and the mixture due the rough surface texture of the rubber aggregate particles.

Figure 3: Slump Obtained for Concrete with 5 % Rubber

Figure 4: Slump Obtained for Concrete with 1% Rubber

PROPERTIES OF HARDENED CONCRETE

Density

The low specific gravity of the rubber chips produced a decrease in the unit weight of the rubberized concrete. In the present study the specific gravity of shredded rubber is 0.946 which yielded the concrete with density 2480 kg/m3 for 5%, 2195.55 kg/m3 for 10% and 2560.98 kg/m3 for 1% without NAOH and 2660.74 kg/m3 with NAOH. Vis a Vis for control mix the density attributes to 2715.06 kg/m3.A considerable decrease in density also can be viewed when CR is replaced in various % in concrete .This virtue can restrict the use of CR in structural concrete. Refer Table 3. Replacing 33% by volume of sand in concrete by plain rubber particles can reduced the concrete density by 10% [17].

Compressive Strength

The compressive strength of concrete is an important parameter which is a main factor for accepting or rejecting a batch of concrete. The compressive strength was tested at 3,7 and 28 days. The results were as shown in the table 3 and in the Figure 5.

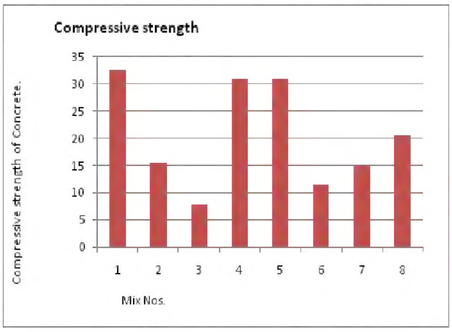

Figure 5: Comparison of Compressive Strength of Mixes

Each value is an average of 3 specimens. It is observed that a reduction of 5.43 % in compressive strength as compared to control mix. An huge reduction of 76.14% for 10% of replacement with shredded rubber and 52.50% reduction with 5% replacement of shredded rubber with reference to the control mix. With reference to the past experiments done by authors, an attempt was made to use NAOH solution to coat the shredded rubber and use the same with 1% replacement in the concrete mix. The shredded rubber chips were dip in saturated NAOH solution for 20 min. They were dried and then washed in running tap water and used in concrete with 1% replacement in concrete.

The test results at 28 days showed a small increase in compressive strength. As shown is Table 3 and Figure 5 Use of crumb rubber in concrete facilitated in decrease of 63.64% strength decrease as compared to the target strength when 5% replacement was done. Replacement of 2 % with CR showed a 52.73 % decrease in compressive strength. However 1% also fails to meet the target strength and thus use of CR in concrete can be restricted only to minor jobs. The inclusion of the waste tires rubber in concrete acted like voids in the matrix. This is because of the weak bond between the waste tires rubber aggregates and concrete matrix. Basic three reasons can be attributed towards the reduction in strength: 1. with the increase in the voids in concrete with maximum replacement of rubber aggregates the decrease in strength was obvious. 2. Shredded rubber act as inclusion in the hardened concrete mass and as a result produced high internal stress that are perpendicular to the direction of applied load. 3 Failure of the sample is due to the waste tire being more elastically deformable than the matrix. When the sample was loaded the crack appears at these softest areas [9]. 4. The presence of rubber aggregate tends to hold the sample fragments together at failure. This trend becomes more marked as the rubber

content increases. This property can be highlighted, researched and can be used for structural applications. Refer figure (6, 7).

Figure 6: Cube with 5% Replacement of SR

Figure 7: Interlocking of SR

Splitting Tensile Strength

The split tensile strength of various mixes are as shown in the Table 3 and Figure 8.

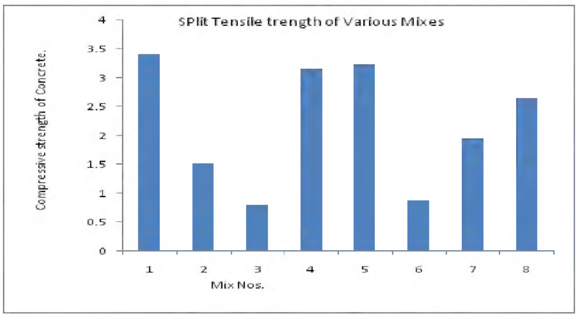

Figure 8: Comparison of Split Tensile Strength of Concrete

Figure 9: Failure Pattern of Concrete Cylinder with SR

A huge reduction in split tensile strength up to 76.59% is observed with concrete with 10% replacement of shredded rubber, similarly an reduction of 55.42% with 5% replacement of shredded rubber. A small reduction of 7.62% is observed when total aggregate content was replaced with 1% shredded tyre rubber. A reduction of 5.24% is observed when total aggregates in concrete were replaced by 1% of shredded rubber treated with NAOH. Use of crumb rubber in concrete facilitated a decrease of 74.19%, 42.81% and 22.28%, when 5%, 2% and 1% replacement with CR was done. However the failure pattern was typically. The cylinders could not break into two halves and were have interlocking shredded tyre aggregates holding. The split tensile strength test samples for control and rubberized concrete are as shown in Figure 9 after testing. It can be observed that, as for the compressive strength tests, the rubberized concrete does not exhibit typical compression failure behavior. The control concrete shows a clean split of the sample into two halves, whereas the rubber aggregate tends to produce a less well defined failure for rubberized concrete, the results show that the splitting tensile strength decreased with increasing rubber aggregate content in a similar manner to that observed for the compressive strength. However, there was a smaller reduction in splitting tensile strength compared to the reduction in the compressive strength.

Flexural Strength

The tests results for flexural strength of concrete, control mix and percentage replacement of SR is as shown in the table 3and Figure 10. An increase of 12% is observed in Flexural strength when shredded rubber were coated with NAOH solution, contradicting many experiments done by authors in the past. A reduction of 9.25 % was observed when shredded rubber without NAOH treatment was replaced by 1%.Due to low tensile strength of concrete as compared to its compressive strength, in lower stresses and before concrete reaches its ultimate strength in the compression region, failure will occur. A lack of good bonding between the rubber particles and the concrete are the reason for failure. However in this study the use of NAOH has also contributed in increasing the compressive strength of concrete with 1% replacement of shredded tyre as aggregates in concrete .Use of CR in concrete contributed towards increase of modulus of rupture when 5% of CR was replaced, however a decrease in the same was seen when 2% and 1% replacement was done.

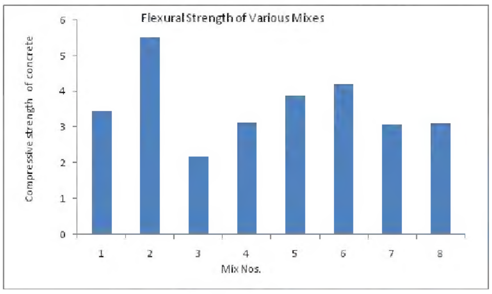

Figure 10: Comparison of Flexural Strength of Concrete

CONCLUSIONS

The above work was an attempt to use SR and CR in concrete with percentage replacement to the total aggregate content. The following points can summarize the findings of the study

- Properties of shredded rubber as compared to the artificial fine aggregate or Conventional coarse aggregate are not very encouraging. However an attempt to use hem in concrete as percentage replacement can be done.
- In the present study, slump is not obtained for the mix with 5%, 10% and 1% SR as a replacement to total

aggregate content. A trend of buckling can also be viewed. However as contrast to the specifications given by IS 100262:2009, all the mixes were easy to work with. It was found that rubberized concrete mixes did not pose any difficulties in term of finishing, casting, or placement, and that a good quality finish can be achieved although additional effort is required to smooth the finish surface. However, increasing the rubber aggregate content reduces the workability of the mix.

- The tests done on hardened concrete show that the use of rubber aggregate in concrete mixes produces a significant reduction in concrete compressive strength with increasing rubber aggregate content. However, if the amount of rubber in the concrete is limited (1% in the project), a normal strength concrete can still be produced. Use of NAOH to coat the shredded rubber contributes to a slight higher compressive strength which can be thought about for potential use in structural applications .However the use of CR in concrete is not advisable and thus can be used only for minor jobs.
- Split tensile strength of concrete with shredded rubber showed a reduction. However 1% replacement of shredded rubber in total aggregate content can be for a concrete with M25 grade. A typical pattern of failure was also observed in cylinders wherein two separate halves were not seen as expected. However, the results also showed an enhancement of concrete flexural strength which could be beneficial in some applications.
- Flexural strength of concrete with percentage replacement tends to increase with decrease in the percentage replacement of SR. However a greater advantage is observed when SR are treated with NAOH. This can be an encouraging study which can lead to use of SR for higher structural applications

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